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ZigBee Technology Application in Wireless Communication Mesh Network of Ice Disaster

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Abstract

The coating ice of transmission lines will threaten the safety of electric power system seriously. In order to obtain the real-time ice-coating data of the transmission lines in ice disaster accurately, this paper designs a real-time monitoring system applied in transmission lines based on ZigBee technology and mesh topology architectures. This system takes advantage of low power consumption of ZigBee technology , self-organization and self-healing of mesh network, and uses the F-AODVjr(F-Ad hoc On-Demand Distance Vector Routing) to establish a ZigBee wireless communication mesh network. A simulating demonstration is given in the end with the discussing of the system's feasibility and practicability.

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Keywords: ice-coating; transmission lines; ZigBee; mesh network; F-AODVjr algorithm; ice disaster

1. Introduction

Ice disaster, as a common natural disaster globally, has a sort of destructiveness, which does a lot of damage to transmission lines every year. The reasons usually are low temperature, freezing rain and snow weather in a large

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range for a long time. Thick ice-coating on the transmission lines may cause serious accidents in power system. Therefore, it is of great importance to monitor the over-head transmission lines ice-coating status and transmit real-time ice-coating data to the power system dispatch and control center by communication channel. The communication channel can be wired network or wireless network. Nowadays the wireless network has becomes more and more popular and is the future trend. Currently, the main means of wireless communication network in short distance are: infrared, Wi-Fi, home RF, Bluetooth, ZigBee, etc[1]. Among them, the infrared is a point-to- point transmit, although it has good speed, its transmit line is likely to be blocked by other objects. It also has difficulties in building a flexible wireless communication, for its effective communication range is just about 1-3 meters. Wi-Fi has the advantages of high transmit rate and wide effective communication range, which can reach 300 meters in a float area, but it is based on the 802.11b standard, with a high cost and high power consumption. It can just work for 1-3 hours before its batteries be charged again, so Wi-Fi is not suitable for the long-time working wireless communication network which worked in the extreme weather. Home RF has a shortcoming in anti-interference. Bluetooth's effective communication range can reach up to 10 meters, but its basic structure based on microgrid leading to the result that a Bluetooth coordinator can just allow 7 slave devices to communicate with it, so it can not be used to build a wireless communication network in large area power system. On the other hand, ZigBee has the advantages of large effective communication range, low power consumption and large network capacity[2].Taking account of the working environment and ZigBee's advantages, this paper designs a scheme to build a wireless communication mesh network based on ZigBee technology. It can be used to transmit the real-time ice-coating data of transmission lines.

This paper proposed that using the ZigBee technology to establish a ZigBee wireless communication mesh network and send the coating ice data, collected by sensors, to ZigBee Routers via ZigBee Terminals, and then, the data will be transferred to the ZigBee Coordinators by ZigBee Routers and send to the Monitoring Center at last. In this case, ZigBee technology and the advantages of self-healing ability of mesh network can be combined, which makes the transmission of the coating ice data more reliable and safer.

2. ZigBee topology structure

2.1. Device classification of ZigBee

Since ZigBee abides by the wireless network specification stipulated by IEE802.15.4 protocol, its nodes in the network can be divided into full function and reduced function nodes according to IEE802.15.4. Meanwhile, on the basis of function, its nodes can also be classified into ZigBee coordinator, router and terminal device. The first two can communicate with any devices while the third one can only exchange information with the router which is connected to it. Information exchange between two terminal devices even needs to depend on the router to transmit. Each kind of topology structure has its own advantages and defects for that there is different amount of nodes. The following is some analysis and comparison on different Zigbee topology structure, which will help us to choose correct network structure and understand the characteristic of these topologies.

2.2. ZigBee network topology structure

Network topology structure of ZigBee can be divided into star, tree and net configuration[3].

Star structure: As the simplest one among the three, its center is ZigBee coordinator with the terminal device directly communicating with the coordinator. The coordinator is responsible for transmitting information if there is communication between two terminals. Although star structure is pretty simple and low cost, it is poor in flexibility. If there are too many nodes, the coordinator will be overburdened. And if there are not enough nodes, then the communication network will not be so effective. Therefore, star structure can not apply to the wireless communication network construction under the situation of ice disaster.

Tree structure: Tree structure is more complicated than star structure. It contains ZigBee coordinator and router which can communicate with both terminals and coordinator. Such kind of routing approach is very simple and can expand network coverage area. However, this model structure is with higher risk under extreme weather for that once there is a node disconnected from network, other nodes which connected to it will also fall off.

Net structure: Net structure is the most complicated one among the three. Router nodes in this structure have equal status. So it is a kind of PPN, having the characteristic of automatic establishment and maintenance for that it can communicate with both terminals and coordinator, but also the nodes within its own communication range. If there is any malfunction of one node, the node which is connected to it will send information to another node within its communication area. Such feature can not only enable information transmitted through various pathways, but also improve security.

The application background of ZigBee wireless communication network in this paper is monitoring ice-coating thickness information under ice condition in long time and wide range. Therefore, in order to make sure that devices can resist interference from rugged environment, we shall select net structure which most conforms to the requirement of electrical power system on communication stability and communication device to resist external force. This kind of wireless communication structure is equipped with extremely strong adaptability and practical value.

3. ZigBee network communication process

3.1. Function of ZigBee protocol stack and main layer

The architecture diagram of ZigBee protocol stack is shown in Fig. 1. This paper will narrate the wireless networking procedure through expressing PHY, MAC, network layer and application layer[4].

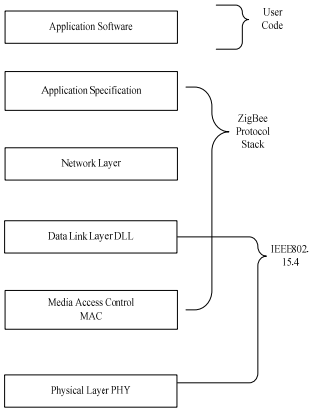

Fig.1. Protocal stack frame diagram of ZigBee.

PHY: Located in the bottom layer of ZigBee protocol stack, it is used to define the connector between wireless channel and MAC layer, activate and unlock wireless transmitter, inspect channel energy, choose channel frequency, output and receive data.

MAC: It is used to generate network signal of coordinator, receive data of network layer, transmit data between equipotent substances and guarantee point-to-point connection in ZigBee network.

Network layer: as the core of ZigBee protocol, it can operate MAC layer with the main function of proving service connector to application layer, giving security that the coordinator and router will allow devices join and quit the network, controlling receiver's initiation and receiving time.

Application layer: It is mainly used to maintain binding table, transmitting information between bound devices, define the role of device in network, establish security relations between network devices, etc.

3.2. New network establishment by ZigBee router

The networking procedure is shown in Fig. 2 when one node is the router node which has not yet established network.

Firstly, the network layer of this coordinator will send energy channel inspection signal to MAC layer. The MAC layer will automatically check whether there is energy channel that has allowable energy level. If there is not such one channel, it will make one signal get back to application layer; if there exists, it will choose a suitable one and distribute a PANId value and judge it whether there is conflict with the original APNId[5,6]. If yes, another random and unique value will be obtained again. Next, the network layer writes this value into MAC layer's PANID attribute together with the address of coordinator. Finally, network layer informs application layer to operate new network. Thus, the node has established a new network which is accessible to devices.

Fig.2. Flow chart of ZigBee router to establish new network.

4. F-AODVJR Zigbee mesh network algorithm

F-AODVjr algorithm is the improved edition of AODVjr(Ad hoc On-Demand DistanceVector Routing)[7]. Compared with the latter one, the former algorithm has advantages of lower consumption of energy and higher survival rate of nodes.

F-AODVjr algorithm can help to distinguish which node is lack of energy and which one is abundant according to the rest energy and level of energy threshold partition node. Meanwhile, it will make the node with sufficient energy play main routing role to decrease the amount of died nodes, reducing node death rate.

In F-AODVjr algorithm, an energy threshold $E_{x(n)}$ is set which is dynamically updated and define that the node whose rest energy is more than $E_{x(n)}$ is considered as sufficient energy node, while less as deficient node. The

sufficient one will be used to transmit data. The deficient one used only to transfer data packet of the destination node within one kind of range or receive destination node's own data grouping. Calculate $E_{x(n)}$ as follows.

$$E_{x(n)} = \begin{cases} \varepsilon\sqrt{E_0} & n = 1 \\ E_{x(n-1)} - \dfrac{\sigma}{n}\sqrt{E_0} & 1 < n < N_{total} \end{cases} \tag{1}$$

When n=1, then $E_{x(1)} = \varepsilon\sqrt{E_0}$ and $E_{x(1)}$ is the initial energy threshold set by the network, ε is the specific coefficient to adjust the setting of the initial threshold. $E_{x(n-1)}$ stands for the energy threshold before update and σ is a certain coefficient to control decreasing speed of the energy threshold. N_{total} is on behalf of the total node amount. It is a kind of constant while n is a variable. Set two interior counters C1 and C2 for ZigBee coordinator. If there is one node whose rest energy is lower than the current value $E_{x(n)}$, the coordinator then shall send information of this node to make the count value of C1 increase 1. According to the value of C1, the coordinator can calculate the number ratio q of deficient nodes and the total nodes. Set a threshold $E_{treshold}(0 < E_{treshold} < 1)$. When $q > E_{treshold}$, the coordinator makes the value of C2 increase 1 and n value is representative of C2. Thus, when n changes to increase 1, $E_{x(n)}$ value will finish one update. Afterwards, adjust C1 to 0 and keep C2 unchanged. Then the value of $E_{x(n)}$ can be obtained..

$$\begin{cases} E_{x(1)} = \varepsilon\sqrt{E_0} \\ E_{x(2)} = E_{x(1)} - \dfrac{\sigma}{2} \times \sqrt{E_0} \\ \cdots \\ E_{x(n)} = E_{x(n-1)} - \dfrac{\sigma}{n} \times \sqrt{E_0} = E_{x(1)} - \dfrac{\sigma}{2} \times \sqrt{E_0} - \cdots - \dfrac{\sigma}{n} \times \sqrt{E_0} \end{cases} \tag{2}$$

It is known from $E_{x(n)}$ calculating method that at the initial stage of network operation, energy threshold $E_{x(n)}$ decreases slowly and when n increases, the decreasing range of $E_{x(n)}$ value becomes smaller and smaller. In the later period, node energy is generally insufficient. F-AODVjr algorithm can enable most of the nodes to participate routing transmission as sufficient energy nodes for that its energy decreasing range becomes slower and slower. Such method can avoid the phenomenon of network congestion caused by small quantity of nodes, thus reducing energy waste.

5. ZigBee wireless communication network in ice disaster

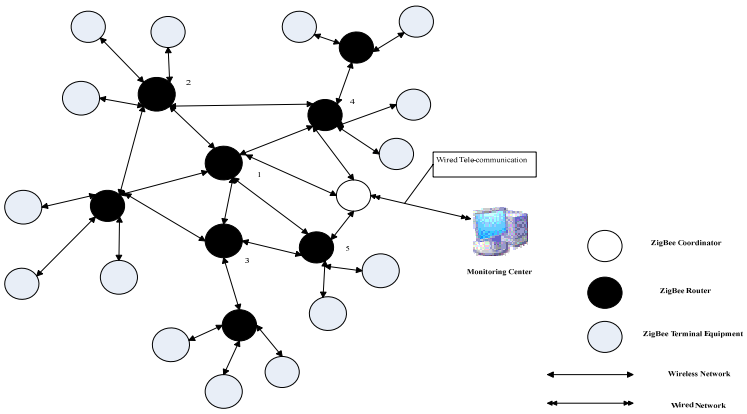

Fig.3. Simulating graph of ZigBee wireless communication mesh network.

As shown in Fig. 3 is the simulated diagram of ZigBee mesh wireless communication network. There will be ice

coating on transmission lines under the heavy weather such as rainy, snowy or frozen for long time and wide area. Such phenomena may cause power tower icing and tilt, conductor galloping, flashover or even blackout[8]. Besides, heavy weather condition and features of transmission line erection site will also cause difficulties in repairing process and take longer time to repair, which may causes serious influence on people's production activity. Hence, it is very important for us to do a good job of monitoring work on transmission line. Use the ZigBee mesh wireless communication network shown in Fig. 3 can be a potentially efficient way to solve the problem. Firstly, combine various sensors and ZigBee reduced function components as terminal device. Then install it on the transmission line. Next, the reduced function component will transmit various real time data collected from the circuit by the sensor to the connected router. The connected router will find out the best communication pathway through F-AODVjr algorithm. Afterwards, the real time data will be sent to other relevant router and finally to the coordinator. And the coordinator will transfer the information to monitoring center through wire communication cable. Thus, a complete information flow path has informed. In this system, one same message has multiple communication pathways. Even there is any node malfunction that causes failure of one, this message can also be transmitted through other ways. It is greatly helpful if this point can be applied to transmission line monitoring system in ice disaster. For example, if there appears mechanical malfunction of node 1 in figure 4 because of tower collapse, and accordingly, the communication pathway (going through node 1) between node 2 and 3 and coordinator disconnects, node 2 and 3 will automatically search adjacent node 4 and 5 to respectively send networking request. Then node 4 and 5 will transmit the information to the coordinator and finally, the message will be sent to monitoring center. Besides, this kind of mesh wireless communication network can make good use of router's information transmission ability to expand its communication range, reducing dependence of wireless communication on base station at the present stage and saving cost.

6. Conclusion

This paper proposed a scheme to transmit real-time data of transmission line ice-coating thickness in ice disaster based on ZigBee wireless communication mesh network. Taking the advantages of ZigBee technology, low power consumption, strong anti-interference ability, flexible networking, low cost, suitable effective communication range, and mesh network's reliability, self-organization and self-healing, this kind of wireless communication mesh network strengthens the safety and forcefulness of the communication system. The method proposed in this paper is expected to offer efficient effects in monitoring and early warning in transmission lines, as well as basis for disaster prevention and emergency repair in power system.

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